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APOLLO AND THE UNMANNED PROGRAM

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APOLLO AND THE UNMANNED PROGRAM

October 30, 1962

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APOLLO AND THE UNMANNED PROGRAM

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Abstract

The conclusions reached from the arguments in the main body of the text are summarized here for convenience of the reader.

The current situation of the support for Apollo from the unmanned program can be stated as follows:

1. Less than a satisfactory minimum of design input information will be available.
2. Little design modification data will be obtained in time.
3. Definitive design confirmation data, coupled with a very conservative Apollo design, is a requirement.
4. The main defect is a lack of capability to obtain sufficient information for the construction of statistical models of the factors with any reasonable confidence level.
5. Continuing effort to revise and define the information required is highly desirable.

The current situation is summarized in Table I.

A summary of specific recommendations is given below:

1. Ranger Program:
   a. The early information required concerning lunar phenomena should be obtained from the Ranger program. Necessary extensions to ensure adequate confidence levels should be planned now on the basis of statistical design.
   b. Studies should be initiated to determine optimum payloads for the later stages of the Ranger program.
   c. A reliability improvement program should be implemented as soon as possible.
2. Surveyor Program:
   a. Consideration should be given to alternate vehicles for Surveyor payloads to ensure the earliest possible schedule.
   b. Payload studies should be initiated to ensure that Surveyor experiments augment rather than duplicate the Ranger program.
3. Lunar Logistic System:

   A study should be initiated to determine an optimum payload for the LLV to enable design confirmation data to be obtained at the proposed Apollo landing site.

4. Micrometeorite Program:

   a. The proposals for the S65 satellite should be defined and implemented at the earliest possible date.

   b. The feasibility should be studied of micrometeorite experiments with sufficient exposure to determine directly the flux data of interest to Apollo.

   c. Earth-based hypervelocity experiments should be encouraged, particularly in any attempts to study impact phenomena at naturally occurring velocities.

5. Radiation Program:

   The instrumentation of currently planned radiation probes should be scrutinized to ensure that they are capable of providing a maximum amount of information concerning solar proton events.

6. Lunar Imagery:

   Recent advances in earth-based and balloon-based telescopic observation should be utilized in the preparation of necessary photomosaics and maps of the lunar surface.

TABLE I

FUNCTIONAL USE OF DATA

Factors	Design Input	Design Modif.	Hardw. Modif.	Design Confirm.	Landing Decisions
Meteoroids					
(a) Cislunar	Poor	Fair	Poor	Poor	
(b) Lunar Surface	Poor	Fair	Fair	Poor	
Radiation					
(a) Radiation Belts	Good	Good	Good	Good	
(b) Solar Proton Events	Fair	Good	Good	Good	
Lunar Surface					
(a) General	Poor	Fair	Fair	Poor	
(b) Landing Gear	Poor	Fair	Fair	Fair	
Communication and Radar	Fair	Good	Good	Good	
Maps and Photo-mosaics	Poor	Fair	Good	Good	Good
Selenodetic Constants	Poor	Fair	Good	Good	Good

Definitions:
- POOR: Limited qualitative or inferred information
- FAIR: Pertinent information - less than minimum requirements
- GOOD: Approximates minimum requirements

Note: In most cases it is unlikely that a statistically significant amount of data will be provided.

APOLLO AND THE UNMANNED PROGRAM

1.0 Introduction

This study is an attempt to summarize and place in proper perspective the information on space environment needed to develop a sound Apollo program. We have also assembled data on the information collecting capabilities of the unmanned program as it now exists in the Office of Space Sciences.

It is clear from even a brief study that choices will have to be made in order to fill the most urgent and important needs for environmental information. Moreover, these decisions will be difficult because of the present range of uncertainties in our knowledge.

There are many ways of classifying the requirements for information. We have chosen three categories: catastrophic hazards, design trade-off constraints, and operational needs. By choosing such a classification we are emphasizing the effect the information has on the Apollo program rather than, for example, a classification in terms of physical processes. The latter would, of course, be the proper framework for a space scientist.

We will be discussing each of the categories of information in some detail below, but a few general comments will be useful at this stage to point up the distinguishing features between catastrophic hazards and design trade-off constraints.

Logic dictates that one first identify conceptually those characteristics of the space environment which could lead to failure of the Apollo mission. In doing this we find there are certain items, such as meteor impact, which are random events. No matter how careful the design, there is always a finite probability of failure. It is important to keep track of these items so that one can make some estimates of the probability of success of the mission. The information required for the safe and most effective design of the Apollo system in many cases overlaps those items considered under catastrophic hazards; indeed, as we learn more about the space hazard, it may be possible by proper design to remove completely some of the catastrophic hazards. Even at this time, for example, we have sufficient information to know that Van Allen belt radiation is not a catastrophic hazard. It will require considerably more information on these belts before we are able to produce an optimum design of the spacecraft.

Following these considerations, this document presents an evaluation of the capability of the present unmanned program to provide the necessary information. Finally, specific conclusions are drawn and suggestions made.

2.0 Information Requirements for Project Apollo

2.1 Priority Scale

To determine the extent to which information is required from unmanned space probes, it is useful to measure the various items against some priority scale. Such a priority scale, consisting of three categories, is defined below.

(a) Catastrophic Hazards: Factors which force abandonment of the chosen mode if discovered prior to flight, abort of the mission if discovered during flight, or failure of the mission if undiscovered. Sufficient information concerning these factors is required to allow the mission/risk to be predetermined.

(b) Design Trade-Off Constraints: Factors which impose constraints on the design of the spacecraft with, in general, a weight or capability penalty which increases with the severity of the factor. This is an expected situation and can be tolerated by proper design based on well substantiated information.

(c) Operational Needs: Factors which affect the planning and performance of the mission but do not affect spacecraft design. Information concerning these factors is required to optimize the performance of the mission flight plan.

2.2 Catastrophic Hazards

There are at present several possible items in this category: meteoroidal impacts, lunar surface interactions, solar proton events. A wide divergence of opinion exists on the probability of any one of the above events being of consequence. This disagreement has arisen in part from the lack of specific information and in part from personal bias. However, the desire for a high probability of mission success and an even higher probability of crew survival suggests a conservative attitude which requires the elimination of "reasonable doubt".

2.2.1 Meteoroidal Impact

The undesirability of puncture of the spacecraft (CM and LEM in particular) or of a space suit is obvious. The present uncertainty in estimates of micrometeoroid flux in the size-range of interest for Apollo is approximately 10^3.(1) This arises from uncertainties in present measurements and from the fact that no direct measurements in the mass range of interest have been made. This uncertainty is coupled with a lack of information concerning hypervelocity impact phenomena at the naturally occurring velocities. With these uncertainties, estimates for an Apollo mission can range from 1% probability of puncture of 6.0 cm skin, to 1% probability of puncture of 0.2 cm skin.

Adequate information for Apollo would come from penetration depths measured on Apollo capsules with a total exposure (area x time exposed) of about ten times the Apollo exposure ($6 \times 10^7 m^2 sec$). A reasonable approximation would be flux data for such an exposure coupled with laboratory measurements of hypervelocity phenomena at naturally occurring velocities (10-70 km/sec) with particles in the mass range of interest (approximately 10^{-2} to 10^{-4} gm).

2.2.2 Solar Proton Events

Four of the thirty solar proton events which have been recently studied had an estimated integrated flux of greater than 2×10^9 protons/cm^2 of energy > 30 mev.(2) This would provide a semi-lethal dose (>450 rem) for a relatively unshielded man (i.e. 1 gm/cm^2 shielding). Under these conditions an astronaut on a ten-day Apollo mission would have a 0.99 probability of receiving less than 30 rem with 9 gm/cm^2 shielding and less than 90 rem with the current shielding of the Apollo CM.

However, because of the limited number of events studied and the relatively unknown effects of the phase of the sunspot cycle, there is insufficient information regarding the probability of occurrence of solar flares much greater than those so far observed.

Improved ability to predict, or to detect early, the occurrence of solar proton events is also necessary to avoid a fatal hazard to astronauts in the Apollo LEM, or in lunar space suits, where heavy shielding is not possible.

A measurement program, encompassing as many events as possible, should be carried out to achieve a better understanding of solar proton events.

2.2.3 Lunar Surface

Possible catastrophic phenomena related to the lunar surface fall into two categories: chemical and mechanical. In neither category can the probability of these hazards be estimated because of the almost complete lack of knowledge concerning the finer details of the lunar surface.

The chemical activity of the lunar surface is unknown. However, it is possible that, because of the vacuum environment and sputtering phenomena, the surface is "clean" (i.e. surface states largely empty).[3] Consequently it is possible that the interaction of rocket engine exhaust gases with this active surface could lead to undesirable exothermic reactions (with reasonable assumptions the energy liberated is about 10^9 calories).

The mechanical phenomena are related to the fragility of the lunar surface. Gold[4] has suggested the possibility of deep dust layers caused by erosion mechanisms (bombardment by protons and micrometeoroids). Others [5,6] have suggested a surface of "rock froth" with equally low bearing strength. Finally, both volcanic[7] and meteoritic[8] models of the moon lead to the existence of fissures or caverns just beneath the surface. In all cases a catastrophically low bearing strength could result.

Measurements of lunar surface properties to reduce these possibilities to an acceptable degree should be required. Of most direct interest would be observations made during the landing of an unmanned spacecraft on the lunar surface.

2.3 Design Trade-Off Factors

The information required to perform adequate design trade-off studies is more detailed than that required to determine a catastrophic hazard. Further, information used for design purposes should, in general, be known to be correct with reasonable certainty to avoid undue weight penalties through overly conservative design. Thus, sufficient repeat measurements are required to reduce the statistical uncertainty to the optimum confidence level.

Consequently, despite the lower priority assigned to design trade-off factors, they represent the great bulk of a resulting measurement program.

2.3.1 Micrometeorite Information

Problems:--

(a) Sufficient determination of penetration probability that, with reasonable certainty, materials and wall thicknesses for Apollo system may be chosen to ensure a 99% probability of crew survival.

(b) Determination of erosion rate to the extent that adequate design measures may be taken to minimize problems.

Information Required:--

(a) Actual flight data on meteoroid flux in the mass range 10^{-2} to 10^{-6} gms.

(b) Determination of velocity and density of meteoroids in this mass range.

(c) Model of hypervelocity phenomena at natural velocities allowing scaling and transfer of data to other materials.

(d) Determination of extent of lunar surface secondary meteoroid problem (at least ratio of lunar surface flux to near-earth flux).

Comments:--

Application of this information to space suit design should be considered. In particular, information concerning the erosion and penetration hazards on the lunar surface is relevant.

2.3.2 Radiation Information

Problems:--

(a) Sufficient determination of the magnitude and time variation of the spectrum of solar proton events that, with reasonable certainty, materials, wall thickness and distribution of other components of the CM and LEM may be chosen to ensure a 99% probability that an emergency dose will not be exceeded.

(b) Acquirement of sufficient prediction ability that return from lunar surface to LEM, LEM to CM, or abort to earth can be performed before occurrence of a flare exceeding the design limits used for the various subsystems.

Information Required:--

(a) Magnitude and time variation of as many solar proton events as possible.

(b) Spectrum and spatial distribution of electron and protons in the natural and artificial belts.

(c) A model of the shielding properties of materials and structures including both primary and secondary radiation with experimental confirmation whenever feasible.

2.3.3 Lunar Surface

Problems:--

(a) Determination of statistical model of lunar surface characteristics relevant to lunar landing and lunar launch of LEM.

(b) Determination of surface characteristics affecting space suit design.

Information Required:--

(a) Probability of 3 ft. size objects (holes, boulders, etc.) within area of landing structure.

(b) Probability of slopes greater than 10°.

(c) Determination of probability of bearing strength greater than 10 lb./sq.in.

(d) Determination of depth of surface layer with low bearing strength (probability of depth greater than 3 ft.).

(e) Determination of chemical activity of surface.

(f) Determination of local variations in the thermal diffusivity of surface.

Comments:--

Space suit design can require knowledge of small scale sharpness of features and fine-detail information on areas of low bearing strength and depths of about 6 ft.

2.3.4 Communications and Radar

Point-to-point communications, as from astronaut-to-astronaut or astronaut-to-LEM, on the lunar surface must use ground wave techniques, since a line-of-sight path may be obstructed. Basic knowledge of the electrical conductivity of the surface is required for design of an optimum system.

Radar altimeters, such as those used in the Surveyor system, have an instrument error of ±4 ft. at a range of 10 to 20 feet above the lunar surface. The effects of the rocket exhaust and surface dust on the radar

system may be evaluated on the earth; however, the unknown depth of penetration before reflection and the reflection characteristics of the lunar surface will increase the expected dispersion in touchdown altitude and velocity. This problem is not catastrophic in nature, but more information may lead to worthwhile savings in landing gear weight and touchdown fuel weight. A better number for the reflectivity of the surface would also improve the system margins in controlling retro fire at high altitudes.

2.4 Operational Needs

The major items to be considered in this category are lunar maps, photomosaics and improved knowledge of the selenodetic constants. They will not be dealt with in detail for two reasons. First, it is difficult to define the quantitative need for any of these items with the current uncertainties in the Apollo system. Second, they are otherwise adequately covered elsewhere (OMSF, "Requirements for Data in Support of Project Apollo").

2.4.1 Lunar Maps and Photomosaics

The improvements in earth-based telescopic lunar imagery through the use of high speed image orthicon techniques should be utilized to the fullest extent. Balloon-based photography should also be considered. The need for maps of the far side of the moon should be evaluated.

2.4.2 Selenodetic Constants

The current uncertainty in selenodetic constants leads to a possible error of approximately 1 mile in perilune. This may be satisfactory.

2.5 Priority-Schedule Matrix

The time periods during which information concerning the various factors should be obtained are shown in Table II. The factors, shown on the left, are given in order of priority. The associated time periods are shown as horizontal lines with the right hand end representing the latest possible date by which the information should be obtained. These dates should be regarded as qualitative, since an exact schedule can only be derived from a detailed examination of the complete Apollo schedule.

On the bottom of the table are shown time periods appropriate for the functional utilization of information obtained at various times.

Ideally, the maximum amount of information should be available as a design input with only that arising from refined design needs being obtained later as design or hardware modification data. Subsequently minimum design confirmation data and the necessary landing decisions information would be obtained.

A more realistic procedure is to require a minimum of early design information to be supported later by more complete information leading to design modifications. This increases the likelihood of expensive and probably time-consuming hardware modifications but still minimizes the need for overly conservative design and subsequent design confirmation.

A less desirable but probably most realistic procedure is to expect less than a satisfactory minimum of design input information supported by incomplete and somewhat uncertain design modification data. Under these circumstances a worst case design philosophy is required with an extensive design confirmation program necessary before the Apollo landings can take place. This is a wasteful process but still satisfactory providing weight margins allow worst case design and providing a definitive design confirmation experiment is certainly available. It should further be pointed out that the use of the manned Apollo system to provide its own design confirmation data is far from ideal. On the other hand, the proposed Lunar Logistic Vehicle appears to possess the necessary capability.

Anything less than this latter procedure is unlikely to be satisfactory. Here it should be emphasized that we are concerned with mission hazards that may be essentially eliminated. Thus it would be a grave error to miss an opportunity of removing a complete class of hazards to mission success by cursory attention to this problem.

3.0 Capability Matrix

The capability of the unmanned program to provide the information required for Project Apollo is shown in Table III in the form of a matrix. The various classes of information are shown in the left column and the relevant sections of the unmanned program in the top row.

Three qualitative ratings are used:

GOOD: Approximates minimum requirements

FAIR: Pertinent information - less than minimum requirements

POOR: Limited qualitative or inferred information.

The Ranger program contains not only the existing payloads but also the extra payloads (LSPC, SURMEC Orbiter) recommended by JPL[9] for support of Apollo. With these additions it is capable of providing adequate early design information. A more detailed discussion of this program has been given earlier.[10]

The 2100 lb. Surveyor Lander payload considered is that most recently proposed by JPL.[11]

It should be remembered that both Ranger and Surveyor programs provide, essentially, point measurements on the lunar surface, whereas what is required is a statistical model of the complete zone for Apollo landings. Even under optimum circumstances (i.e. virtually uniform lunar surface) a number of point measurements will be required. The number is dictated by the certainty required according to the standard principles of statistical design of experiments. This in turn dictates either a higher probability of mission success in the unmanned program than is now current or a greatly enlarged program. It should also be pointed out, in this regard, that both Ranger and Surveyor Orbiters will aid in providing a framework for a statistical model and should not be abandoned lightly.

General comments on the adequacy of the present program are given at the right hand of the matrix. The specific comments below offer some justification for the attributes assigned to the various programs. Obvious comments have been omitted. The information leading to these comments has been drawn from several sources.[12,13,14]

RANGER 5*

1. The seismic experiment will yield some information about the lunar surface if moonquakes or impacts of large meteoroids are common.
2. Some measure of lunar gravity and hence lunar mass can be obtained from the radar experiment.

RANGER 10-14

3. If Lunar Surface Photo Capsules (LSPC) and Surface Measurement Capsules (SURMEC) are used as payloads,

*Since the time of writing, this probe has been launched and it failed to achieve its objective.

reasonably good information concerning the lunar surface will be obtained.

LIGHT WEIGHT ORBITER (Ranger weight class)

4. The fair rating is given because the photo coverage can be used to correlate "point" coverage of the TV impacter and LSPC payloads. (An RCA and an STL Agena based orbiter are both under study.)

SURVEYOR (2100 lb.)

5. Micrometeorite payload is small (4 lb.) but should be sufficient to provide lunar surface flux data which can be compared to that near earth.

SURVEYOR ORBITER

6. Since this spacecraft will have a long life in lunar orbit it could act as a convenient carrier for meteoroid and solar flare experiments.

S55 and S65

7. Fair rating is given because neither experiment will give direct, statistically significant information concerning the flux corresponding to an Apollo exposure.

4.0 Schedule Considerations

The launch schedules for the unmanned programs which can provide information in support of the Apollo project are shown in Table IV. They will be discussed in three groups: the lunar program, the micrometeorite program, and the radiation program.

4.1 Lunar Program

The only design input information available will come from the four remaining Ranger flights and the five planned extension flights. If the lunar surface payloads (LSPC and SURMEC) are available for the extension flights, some capability for obtaining lunar surface information exists. This, however, is modified by the lack of reliability of the Ranger system and the fact that the information will be insufficient for the construction of any acceptable statistical model of the surface properties. A possible exception to this statement, if the proposed Ranger Orbiter is in fact flown, is the information regarding the topographic features of the moon.

The schedule shown for the Surveyor program assumes that no more slippage occurs in the Centaur program or that some alternative vehicle is available. The instrumentation on the Surveyor is superior to that on Ranger; however, the same modifying criticisms stated for Ranger apply. It further appears probable that the information is most likely to be obtained during the hardware modification-design confirmation time period.

4.2 Micrometeorite Program

The S55 satellite is the only definitely scheduled flight which is capable of yielding any definitive information on micrometeoroids. This will yield inadequate design input information.

The planned, but not yet defined, S65 will fly in time to provide design modification data. On the basis of proposals for the S65 it will provide good penetration information but will still give inadequate exposure.

No other micrometeorite flight is scheduled, with the possible exception of applications of Apollo development flights. Examination of the outer skin of recovered orbiter units might deliver additional useful information.

4.3 Radiation Program

There appears to be an adequate number of flights scheduled to provide design input information on radiation parameters.

5.0 Conclusions

Before discussing any recommendations, two general comments should be made concerning sources of information which have not been fully utilized in this document. First, only a minimum amount of information has been available concerning the opinions of spacecraft designers as to the information they require. Second, it has not been possible to include a statistical analysis of the present program to determine the probability that the necessary information will be obtained with any reasonable confidence level.

A general conclusion can be reached that the situation corresponds to the third case discussed in the Priority-Schedule Matrix, i.e. somewhat less than a satisfactory minimum of design input information with little design

modification data. Consequently, definitive design confirmation data is a requirement coupled with a conservative Apollo design. The main defect is the lack of a capability to obtain sufficient information for statistical models of the various factors to be constructed with any reasonable confidence level.

The second general comment to be made is that it is highly desirable that organized continuing effort be made to revise and define the present estimates of the information required to support the Apollo program.

A summary of specific recommendations is given below:

1. Ranger Program:
   a. The early information required concerning lunar phenomena should be obtained from the extended Ranger program. Necessary extensions to ensure adequate confidence levels should be planned now on the basis of statistical design of the program.
   b. Studies should be initiated to determine optimum payloads for the later stages of the Ranger program.
   c. A reliability improvement program should be implemented as soon as possible.

2. Surveyor Program:
   a. Consideration should be given to alternate vehicles for Surveyor payloads to ensure the earliest possible schedule.
   b. Payload studies should be initiated to ensure that Surveyor experiments augment rather than duplicate the Ranger program.

3. Lunar Logistic System:

   A study should be initiated to determine an optimum payload for the LLV to enable design confirmation data to be obtained at the proposed Apollo landing site. (A preliminary study is now under way and will be reported in detail in a forthcoming report.)

4. Micrometeorite Program:
   a. The proposals for the S65 satellite should be defined and implemented at the earliest possible date.
   b. A study should be made of the feasibility of a micrometeorite experiment with sufficient exposure to determine directly the flux data of interest to Apollo.

c. Earth-based hypervelocity experiments should be encouraged, particularly in any attempts to study impact phenomena at naturally occurring velocities.

d. A study of the outer skins of recovered orbiting shots (e.g. Mercury, Discoverer) may deliver additional information and should be examined.

5. Radiation Program:

The instrumentation of currently planned radiation probes should be scrutinized to ensure that they are capable of providing a maximum amount of information concerning solar proton events.

6. Lunar Imagery:

Recent advances in earth-based and balloon-based telescopic observation should be utilized in the preparation of necessary photomosaics and maps of the lunar surface.

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TABLE II

PRIORITY - SCHEDULE MATRIX

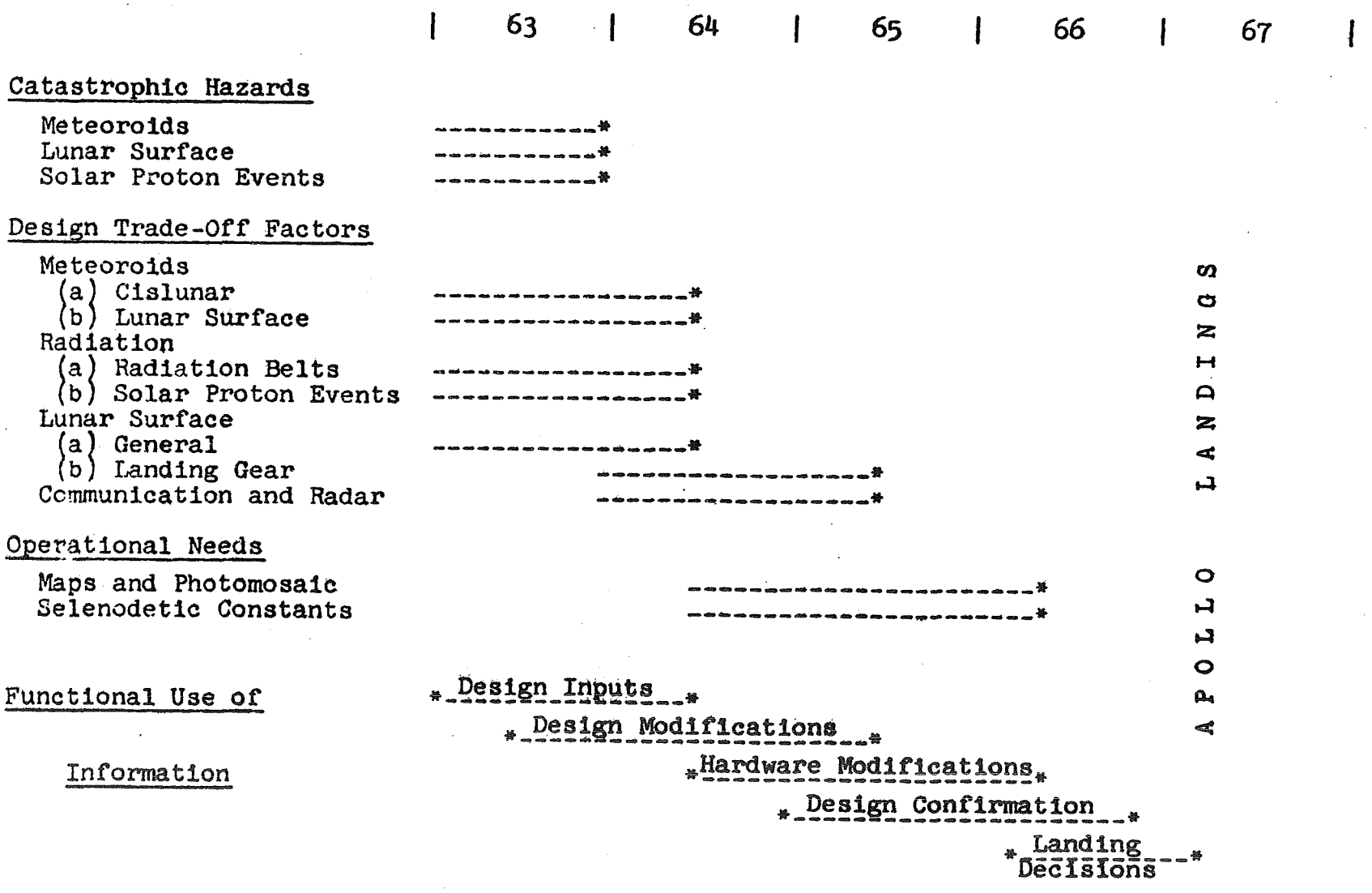

TABLE III

CAPABILITY MATRIX

	RANGER 5	RANGER 6-9 TV IMPACTER	RANGER 10-14 LSPC & SURMEC Only	LIGHT-WEIGHT ORBITER	SURVEYOR (2100 lb.)	SURVEYOR (2500 lb.)	SURVEYOR ORBITER	S55, S65	TELSTAR	S-6	MARINER	S3A	IMP	OSO	EGO	OAO	POGO
CATASTROPHIC HAZARDS																	
Meteoroids	FAILED TO REACH MOON	-	-	-	Poor[5]	Poor	Fair.[6*]	Poor[7]	-	-	Poor	-	Poor	-	Fair	-	-
Lunar Surface		-	Good[3]	Fair[4]	Good	Good	Fair.	-	-	-	-	-	-	-	-	-	-
Solar Proton Events		-	-	-	-	-	Fair.[6*]	-	-	-	Poor	-	Good	Good	Good	Fair	Good.
DESIGN TRADE-OFF FACTORS																	
Meteoroids																	
(a) Cislunar		-	Poor	-	-	-	Fair.[6*]	Poor	-	-	Poor	-	Poor	-	Fair	-	-
(b) Lunar Surface		-	-	-	Good	Good	-	-	-	-	-	-	-	-	-	-	-
Radiation																	
(a) Radiation Belts		Poor	-	-	-	-	Fair.[6*]	-	Good	-	Poor	Good	Good	Good	Good	Fair	Good.
(b) Solar Proton Events		-	-	-	-	-	Fair.[6]	-	-	-	Poor	-	Good	Good	Good	Fair	Good.
Lunar Surface																	
(a) General	Poor[1]	-	Good	Fair	Good	Good	Fair.	-	-	-	-	-	-	-	-	-	-
(b) Landing Gear		-	Fair	-	Good	Good	-	-	-	-	-	-	-	-	-	-	-
Communication and Radar	Fair	-	Fair	Good	-	-	Good.	-	-	-	-	-	-	-	-	-	-
OPERATIONAL NEEDS																	
Maps and Photomosaic		-	-	Good	-	-	Good.	-	-	-	-	-	-	-	-	-	-
Selenodetic Constants	Poor[2]	-	-	Good	Poor	Poor	Good.	-	-	-	-	-	-	-	-	-	-

* If augmented. Numbers - See text.

TABLE IV — SCHEDULES

ASSUMED APOLLO LANDINGS

	1962	1963	1964	1965	1966	1967
RANGER 5 (SEISMIC)	☐ 1					
RANGER 6-9 (TV-IMPACTOR)		☒ 3	☒ 2			
RANGER 10-14 (TV-IMPACTOR OR LUNAR SURFACE)			☒ 3			
LIGHTWEIGHT ORBITER (TV-MAPPING)				● 10	● 20	● 30
SURVEYOR (2100) (LUNAR SURFACE)			☒ 2	☒ 2	● 20	● 30
SURVEYOR (2500) (LUNAR SURFACE)				☒ 1	☒ 1 ● 1	● 20
SURVEYOR ORBITER (TV-MAPPING)						● 20
S-5S, S-6S (MICROMETEOROID)	☒ 1		☒ 1			
TELSTAR (RADIATION BELT)	☒ 2					
S-6 (ATMOSPHERE)	☐ 1	* 1				
MARINER (INTER-PLANETARY RADIATION)	☒ 1		☒ 1			
S-3A (RADIATION BELT)	☒ 1					
IMP (RADIATION)	☒ 1	☒ 1	☒ 1			
OSO (SOLAR FLARES)		* 1				
EGO (RADIATION)		☐ 1				
OAO (RADIATION)				☒ 1		
POGO (POLAR ORBIT RADIATION)			☒ 1			

KEY
- ☒ SCHEDULED
- ☒ PLANNED
- ● PROPOSED
- * UNDER STUDY

—FAILED TO REACH MOON—

DESIGN INPUTS

DESIGN MODIFICATIONS

HARDWARE MODIFICATIONS

LAUNCH DECISIONS

DATA REQUIRED FOR

BELLCOMM
BELL
SYSTEM
INC.